Student Textbook page 589

Q1. (a) $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$

(b) $C_4H_8(g) + 6O_2(g) \rightarrow 4CO_2(g) + 4H_2O(g)$

Q2. $C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g)$

Q3. $2CH_3OH(g) + 3O_2(g) \rightarrow 2CO_2(g) + 4H_2O(g)$

Q4. $C_3H_7COOH(\ell) + 5O_2(g) \rightarrow 4CO_2(g) + 4H_2O(g)$

Q5. $C_6H_{12}O_6(s) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(g)$

Q6. The energy produced in the combustion of a hydrocarbon is from the breaking and reforming of chemical bonds during combustion. The energy required to break apart carbon–hydrogen and carbon–carbon covalent bonds is not as large as the amount of energy released as oxygen–hydrogen (O–H) and carbon–oxygen (C=O) covalent bonds form.

Student Textbook pages 596–597

For full solutions to the practice problems, visit **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, Full Solutions.

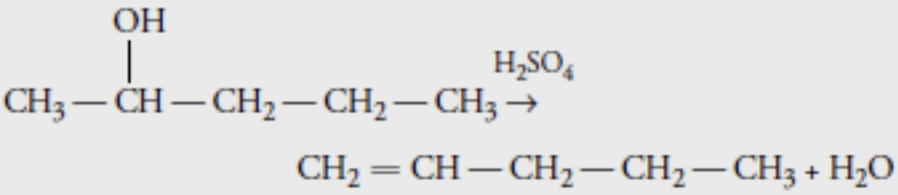
1. (a) addition

(b) esterification

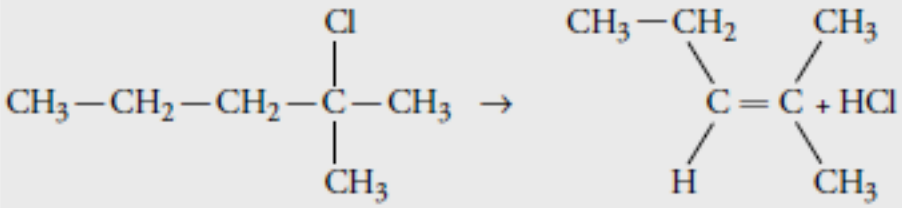
(c) substitution

(d) elimination

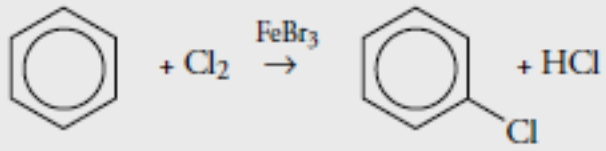
2. (a) pentan-2-ol $\xrightarrow{H_2SO_4}$ pent-1-ene + water



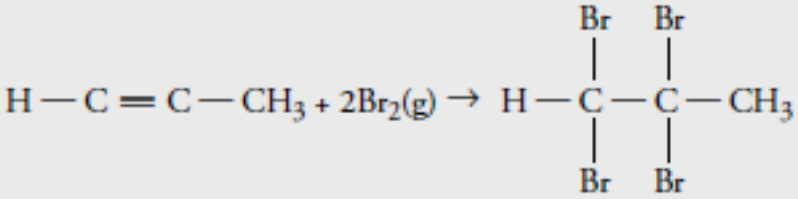
(b) 2-chloro-2-methylpentane →
2-methyl-pent-2-ene + hydrogen chloride



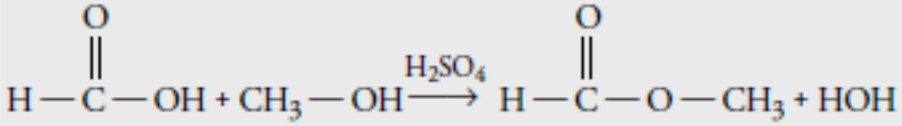
(c) benzene + chlorine gas $\xrightarrow{FeBr_3}$
chlorobenzene + hydrogen chloride



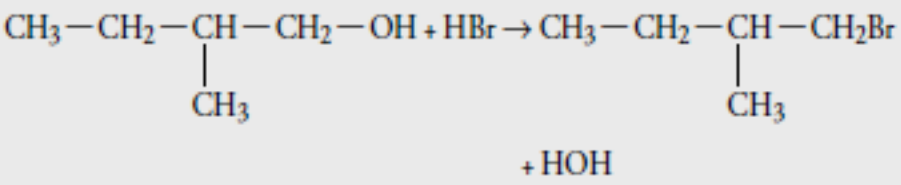
(d) propyne + bromine vapour (excess) →
1,1,2,2-tetrabromopropane



(e) methanol + methanoic acid $\xrightarrow{H_2SO_4}$
methyl methanoate + water



(f) 2-methylbutan-1-ol + hydrogen bromide → 1-bromo-2-methylbutane + water



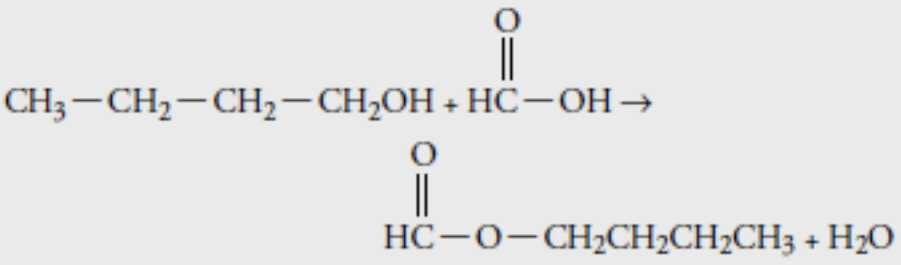
3. **(a)** elimination
   (b) elimination
   (c) substitution
   (d) addition
   (e) esterification
   (f) substitution

4. $CH_2{=}CH - CH_3 + HOH \rightarrow CH_3 - CH(OH) - CH_3$

5. Step 1: An alkyl halide will react with a strong base $OH^-(aq)$ at room temperature to produce an alcohol; in a substitution reaction, butan-1-ol can be made from 1-chlorobutane in this manner.

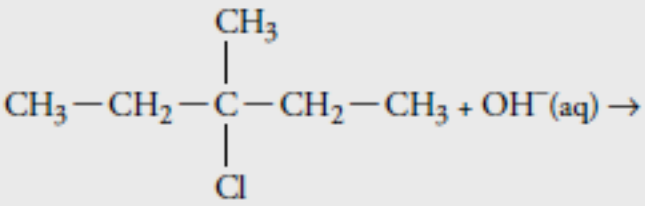
   $CH_3 - CH_2 - CH_2 - CH_2Cl + OH^-(aq) \rightarrow CH_3 - CH_2 - CH_2 - CH_2OH + Cl^-$

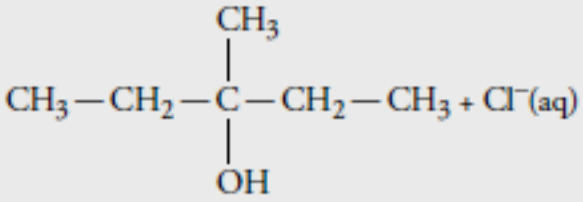
   Step 2: Methanoic acid will react with the butan-1-ol to form butyl methanoate and water.



6. This reaction can be carried out in one step with a substitution reaction in the presence of a strong base.

3-chloro-3-methylpentane + $OH^-(aq) \rightarrow$
3-methylpentan-3-ol + $Cl^-(aq)$





Student Textbook pages 602

1. (a) addition

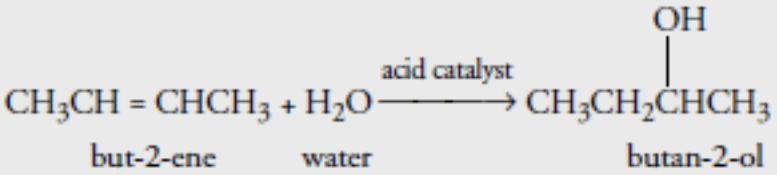
(b) esterification

(c) elimination

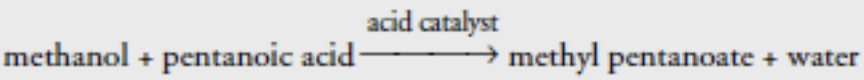
(d) substitution

2. Students should produce answers similar to the following:

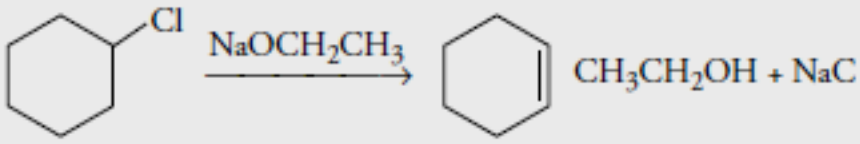
(a) Addition reaction



(b) Esterification reaction

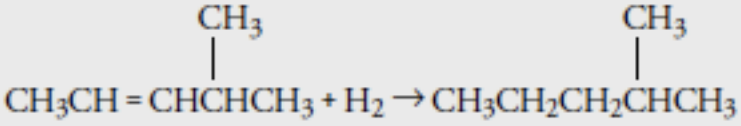


(c) Elimination reaction



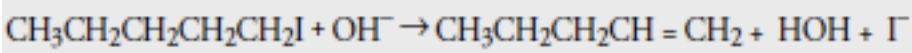
chlorocyclohexane cyclohexene ethanol salt

(d) Addition reaction



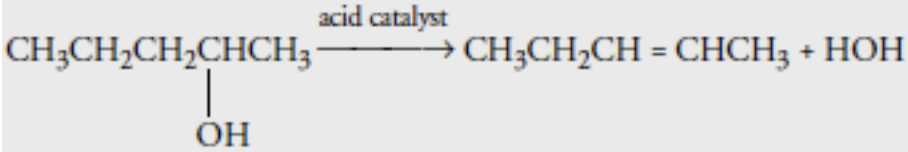
4-methylpent-2-ene hydrogen 2-methylpentane

(e) Elimination reaction



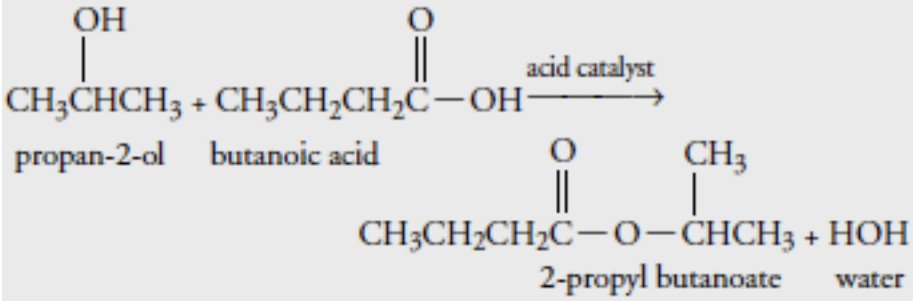
1-iodopentane hydroxide ion pent-1-ene water iodine ion

(f) Elimination reaction



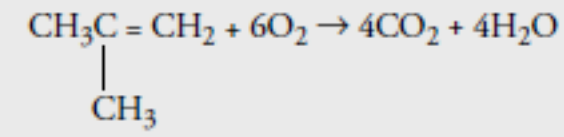
pentan-2-ol pent-2-ene (major) water

(g) Esterification reaction



propan-2-ol butanoic acid 2-propyl butanoate water

(h) Combustion reaction

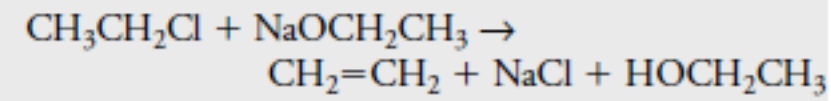


$$CH_3C(CH_3)=CH_2 + 6O_2 \rightarrow 4CO_2 + 4H_2O$$

2-methylprop-2-ene

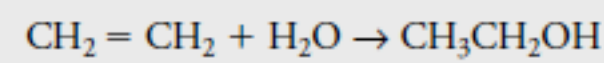
3. Examples of possible answers are listed below.

(a) Elimination reaction



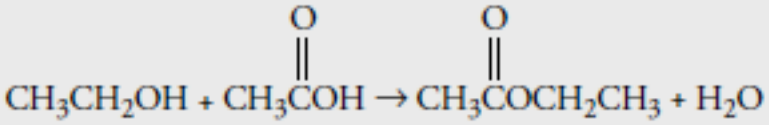
$$CH_3CH_2Cl + NaOCH_2CH_3 \rightarrow CH_2{=}CH_2 + NaCl + HOCH_2CH_3$$

(b) Addition reaction



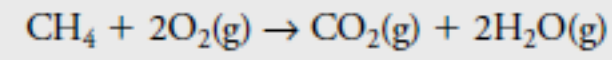
$$CH_2 = CH_2 + H_2O \rightarrow CH_3CH_2OH$$

(c) Esterification reaction



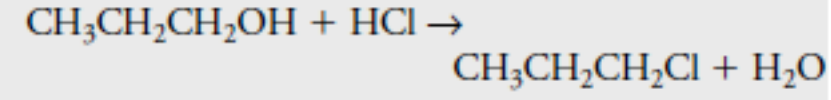
$$CH_3CH_2OH + CH_3COH \rightarrow CH_3COCH_2CH_3 + H_2O$$

(d) Combustion reaction



$$CH_4 + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$$

(e) Substitution reaction



$$CH_3CH_2CH_2OH + HCl \rightarrow CH_3CH_2CH_2Cl + H_2O$$

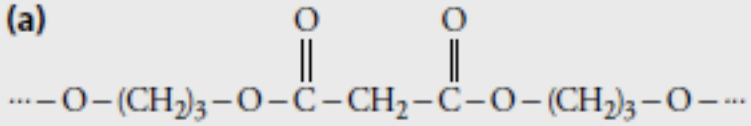
4. The Launch Lab involved an addition reaction whereby two hydroxyl groups were added to the alkene, one on either side of the original double bond. The formation of a brownish precipitate was evidence of the formation of a new substance.

5. Human activities, especially related to combustion of fossil fuels, are contributing many greenhouse gases to the atmosphere. In addition, the cutting down of forests for agricultural lands removes areas where one of the most predominant greenhouse gases produced is naturally removed. The overall severity of the effect is still being debated but the likely result is that the warming effect produced may cause a shift in global air circulations. The corresponding changes to precipitation patterns may lead to widespread changes to the biosphere.
6. HFCs are more potent greenhouse gases than carbon dioxide, so they are one of the gases that are regulated under the Kyoto Protocol.

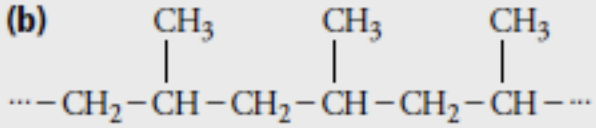
Student Textbook pages 606–607

For full solutions to the practice problems, visit **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, Full Solutions.

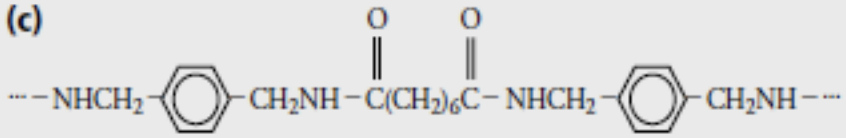
7. polymethylmethacrylate (commonly known as PMMA)
8. **(a)** condensation polymerization
   (b) addition polymerization
   (c) condensation polymerization
9. **(a)**



(b)



(c)



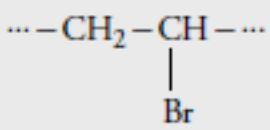
10. **(a)** addition polymer

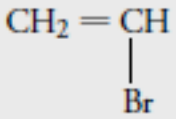
(b) condensation polymer and a polyamide, or nylon

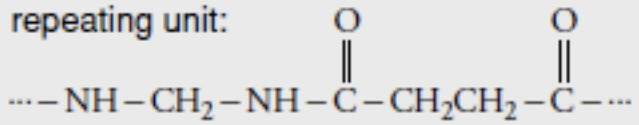
(c) condensation polymer and a polyester

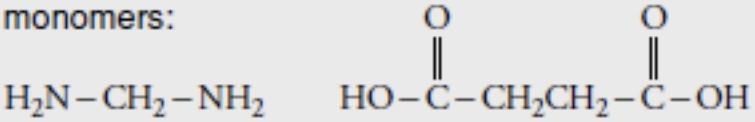
(d) condensation polymer and a polyester

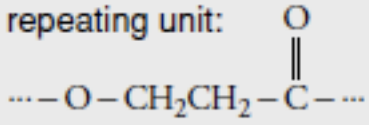
11.

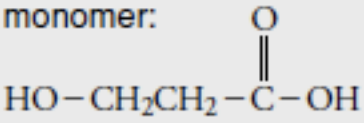
(a) repeating unit: 

monomer: 

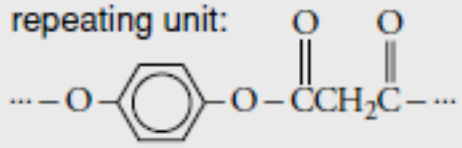
(b) repeating unit: 

monomers: 

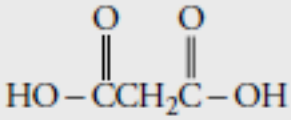
(c) repeating unit: 

monomer: 

(d) repeating unit:



monomers:

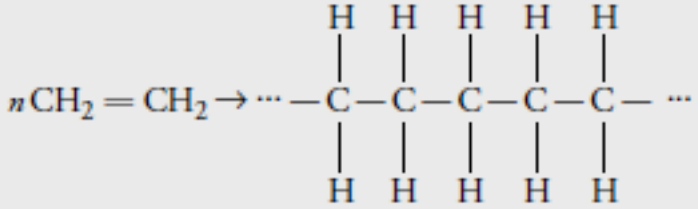


12. **Step 1** Production of ethene. C_2H_4.

An alkyl halide can undergo elimination to produce an alkene when heated in the presence of a strong base, such as sodium ethoxide ($NaOCH_2CH_3(aq)$) mixed with an ethanol solvent.

$$CH_3-CH_2Br \xrightarrow{NaOCH_2CH_3} CH_2=CH_2 + H_2O + Br^-$$

Step 2 Polymerization



Student Textbook page 614

1. **(a)** A major difference between synthetic and natural polymers is how the monomer is obtained. For synthetic polymers the monomers are derived or extracted from petrochemicals, which undergo controlled chemical syntheses.

(b) Examples of natural polymers include cellulose, starch, proteins, and DNA. Three common synthetic polymers are polyethylene, polypropylene, and polyvinyl chloride.

(c) Glucose is the monomer in both cellulose and starch, amino acids are the monomers in proteins, and nucleotides are the monomers in DNA. Polyethylene is composed of ethene monomers, while propene monomers form polypropylene and vinyl chloride monomers form polyvinyl chloride.

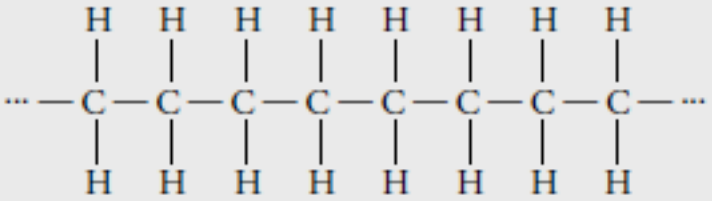
2. The reaction processes are classified as addition reactions and condensation reactions.

3. **(a)** a carboxyl group and an alcohol group

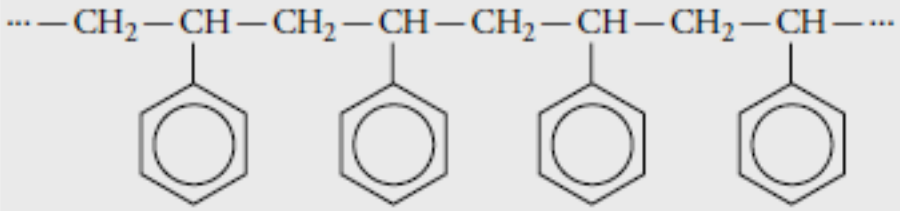
(b) a carboxyl group and an amino group

4. Student answers may depend on whether they use complete, condensed, or line structural formulas.

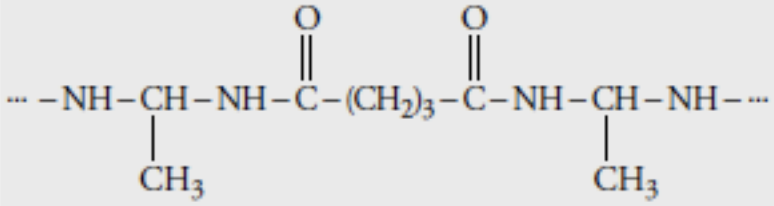
(a) Addition polymerization



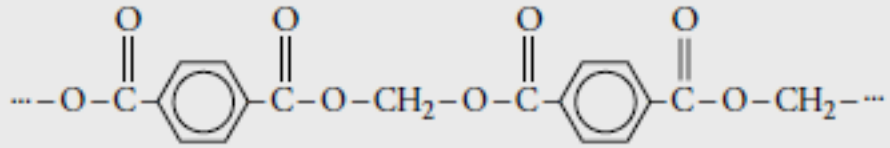
(b) Addition polymerization



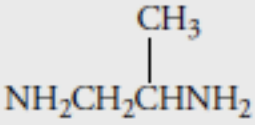
(c) Condensation polymerization

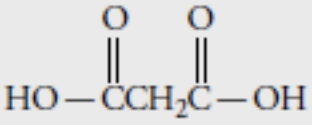


(d) Condensation polymerization

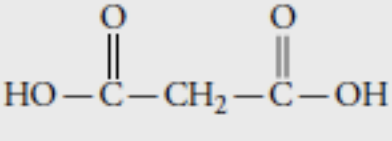


5. (a)





(b)



6. (a) There are several problems associated with society's use of synthetic polymers. The first is that the polymers formed are very stable and do not readily decompose. The living organisms that would normally carry out the decomposition lack the enzymes needed to attack the polymer bonds. The second major problem is that the monomers needed for the polymerization reactions are typically obtained from petrochemical sources, an inherently non-renewable source.

(b) The benefits obtained from synthetic polymers are that they are incredibly stable and have a wide range of properties that can be tailored to fit a particular technological or societal need.

(c) Regardless of the students' opinions, they should be able to provide rationale for their choices. Possible costs/risks that may be listed by the students include increasing levels of plastic garbage, overflowing landfills, and toxic by-products from the production of polymers.

7. The petrochemical industry uses alkanes obtained from fractional distillation of petroleum to prepare alkenes, which can then be modified by the various types of organic reactions to form the desired monomers. A good example is included in the student textbook, which is ethane being forced to undergo an elimination reaction to produce ethene and hydrogen gas. The ethene then undergoes an addition polymerization reaction to form polyethylene.

Student Textbook pages 616–617

Answers to Understanding Concepts Questions

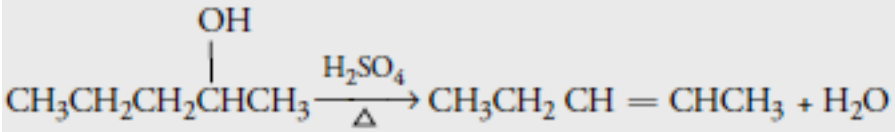
1. (a) A substitution reaction is characterized by a hydrogen atom or functional group being replaced by a different functional group. In this reaction, two compounds react to form two different products, without loss or gain of a multiple bond on the carbon atoms.

$$CH_3CH_2CH_2CH_2OH + HCl \rightarrow CH_3CH_2CH_2CH_2Cl + H_2O$$

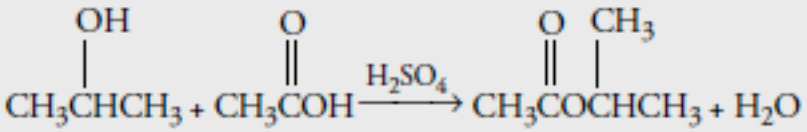
(b) An addition reaction involves reactions of alkenes and alkynes with small molecules, whereby atoms are added to the multiple bond resulting in the loss of that bond. Common small molecules that add to alkenes and alkynes include water, hydrogen, hydrogen halides, and halogens.

$$CH_3-CH=CH_2 + H_2O \rightarrow CH_3-\underset{\displaystyle OH}{\underset{|}{CH}}-CH_3$$

(c) An elimination reaction can be viewed as the reverse of an addition reaction, whereby atoms are removed from two carbon atoms in a reactant and a double bond forms between those two carbons in the organic product.



(d) In a typical esterification reaction a carboxylic acid reacts with an alcohol to form an ester and water.



(e) During a complete combustion reaction a hydrocarbon reacts with oxygen gas in the presence of a spark to produce carbon dioxide gas, water vapour, and energy. If not enough oxygen is present incomplete combustion produces the same products, as well as carbon and/or carbon monoxide.

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$$

2. (a) A polymer is an organic molecule that consists of repeating units called monomers that are linked together by covalent bonds.

(b) A monomer is a small organic molecule that is the repeating unit in a polymer.

(c) Plastic is a synthetic polymer that can be moulded or heated to form specific shapes.

3. (a) elimination reaction

(b) combustion reaction

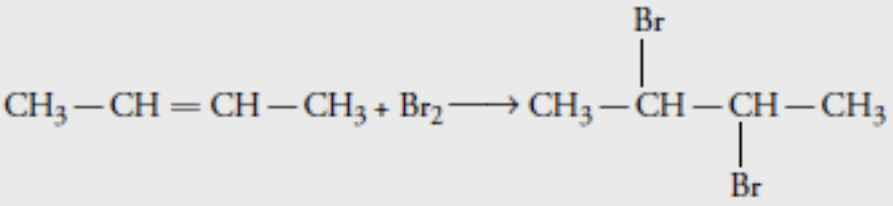
(c) esterification reaction

(d) addition reaction

(e) substitution reaction

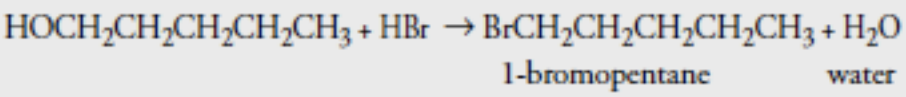
4. Polymers are named after the monomer used to form them. In the case of polyethene, more commonly known as polyethylene, the monomer is ethene.

5. (a)



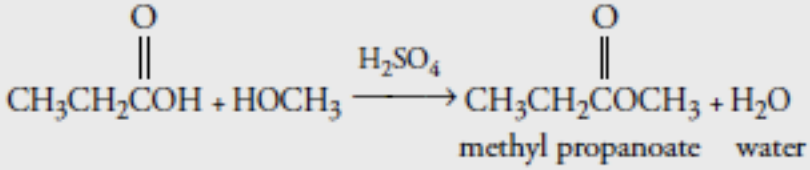
2,3-dibromobutane

(b)



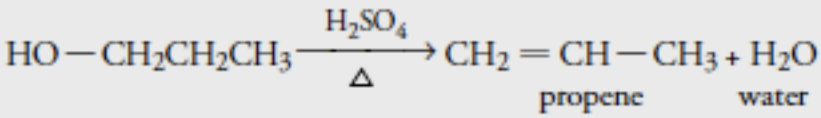
1-bromopentane water

(c)



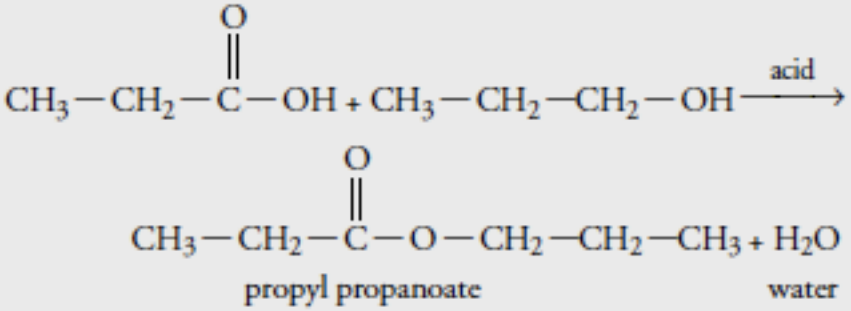
methyl propanoate water

(d)



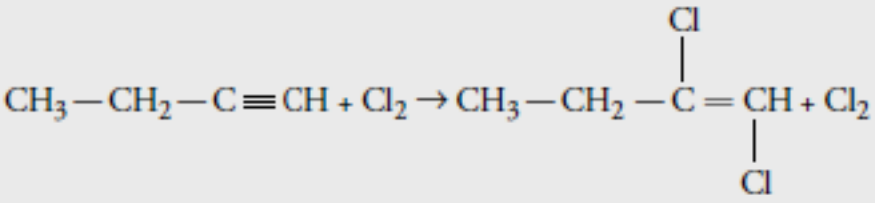
propene water

6. (a)

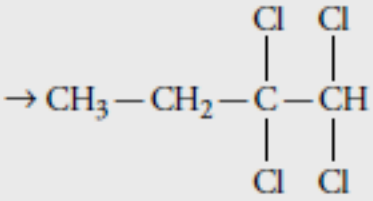


propyl propanoate water

(b)

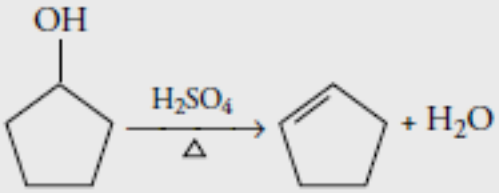


1,2-dichlorobut-1-ene



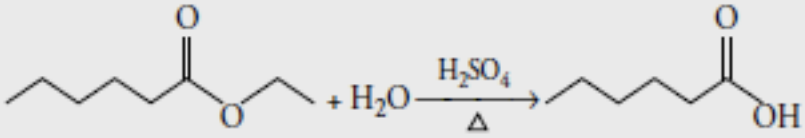
1,1,2,2-tetrachlorobutane

(c)

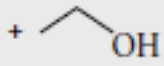


cyclopentene water

(d)

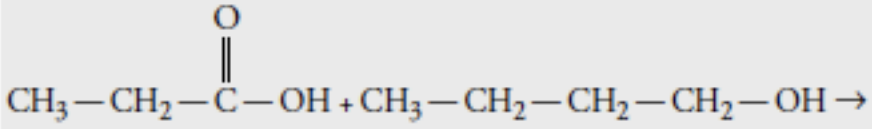


hexanoic acid



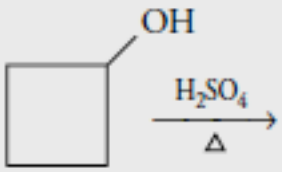
ethanol

7. (a)



propanoic acid butan-1-ol

(b)



cyclobutanol

Answers to Applying Concepts Questions

8. The difference between a polymer and any other large molecule is that polymers are composed of repeating units of monomers. Large molecules are not necessarily composed of monomers. In addition, although the monomers used may be the same, individual polymer synthesis can result in products of varying length.

9. Proteins and starches are classified as polymers because they consist of repeating monomers of amino acids and glucose, respectively.

10. (a) An addition polymerization involves multiple addition reactions of alkene monomers to form polymers that lack the double bond.

$$CH_2=CH_2 \xrightarrow{\text{catalyst}} \cdots -CH_2-CH_2-\cdots$$

(b) A condensation reaction is one in which monomers with two or more functional groups undergo multiple condensation reactions to form a polymer and a second smaller product.

$$HOCH_2CH_2OH + H_2N-\overset{\overset{O}{\|}}{C}-NH_2 \xrightarrow{\text{catalyst}}$$

$$\cdots -CH_2-CH_2- NH-\overset{\overset{O}{\|}}{C}-NH-CH_2-CH_2-\cdots + H_2O$$

11. **(a)** The monomer used to make polypropene is propene, $H_2C = CHCH_3$

(b) Polypropene is an addition polymer.

(c) The common name for this polymer is polypropylene.

12. Although both nylon and polyester are condensation polymers, the difference between the two is that nylon monomers are linked by amide bonds and polyester monomers are linked by ester bonds.

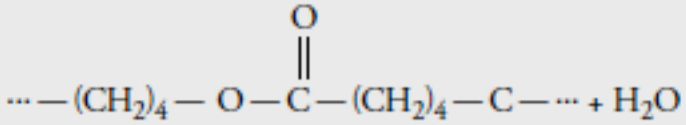
13. A protein is effectively a polyamide because the amino acid monomers are linked by amide bonds.

14. Both cellulose and starch are polymers of glucose monomers. The major difference between them is the orientation of the monomers relative to each other. This difference is due to how the glucose units are linked together. Cellulose contains beta linkages and starch contains alpha linkages. This results in the two molecules having different three-dimensional structures. While we have enzymes in our body that can recognize starch, which allows us to beak it down, we do not contain enzymes to break down cellulose. In addition, starch can also contain branched chains, while cellulose does not. These two molecules also have very different functions within plants. Starch is used as a storage mechanism for extra glucose and cellulose is used as a structural component.

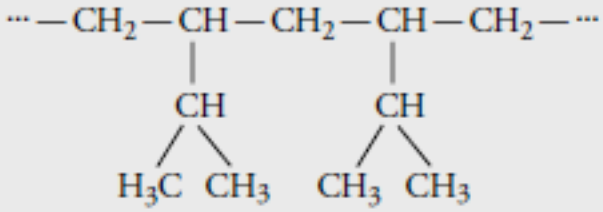
15. The difference between a protein and an amino acid is that amino acids are the monomers used to form the protein.

16. Students should produce structures similar to those below. Answers will depend on the type of structural formulas used to draw the products.

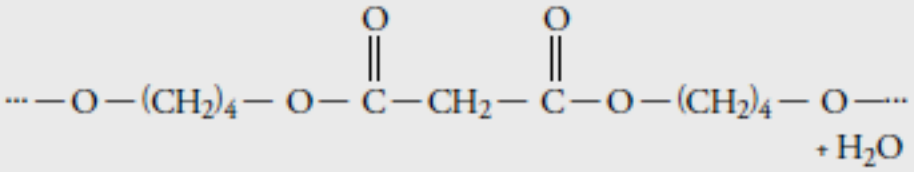
(a)



(b)



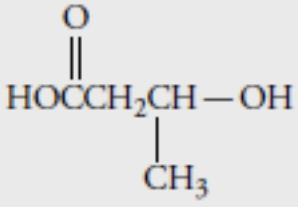
(c)



17. Students should produce structures similar to those below. Answers will depend on the type of formulas used to draw the monomers.

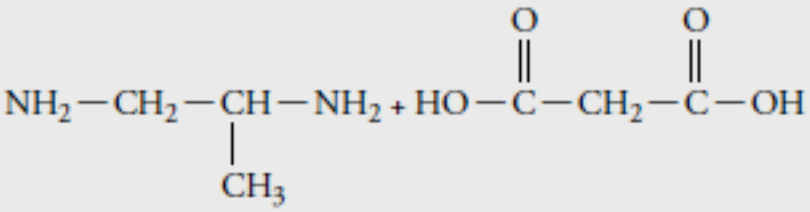
(a) $CH_2 = CH_2$

(b)

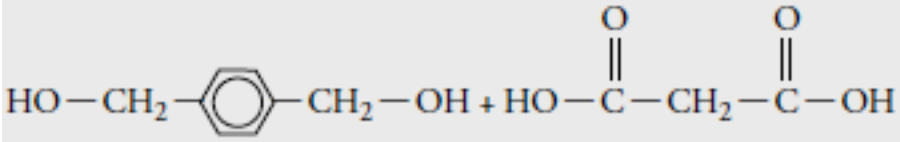


(c) $CH_2 = CHCH_2CH_3$

(d)

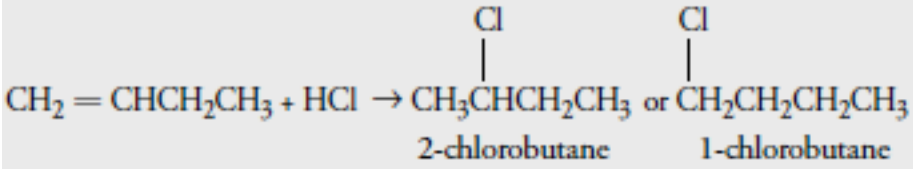


(e)



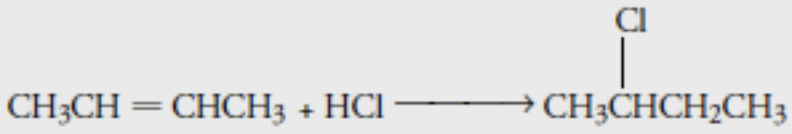
Answers to Making Connections Questions

18. Due to the location of the double bond in but-1-ene, there are two possible configurations when adding HCl across the double bond.



However, according to Markovnikov's rule, the hydrogen atom of HCl will attach to the carbon of the double bond that is already bonded to the most hydrogen atoms. Therefore, 2-chlorobutane is the major product formed.

When but-2-ene is used instead, the symmetrical nature of the molecule produces only one isomer,

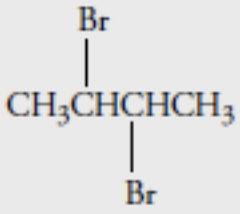


19. (a) Place the sample of oil or fat into a test tube. Add 10 to 15 drops of bromine water to the test tube, cover the end of the tube with a rubber stopper and shake. The loss of the reddish-brown bromine color is evidence for the addition of bromine atoms across a carbon-carbon double bond.

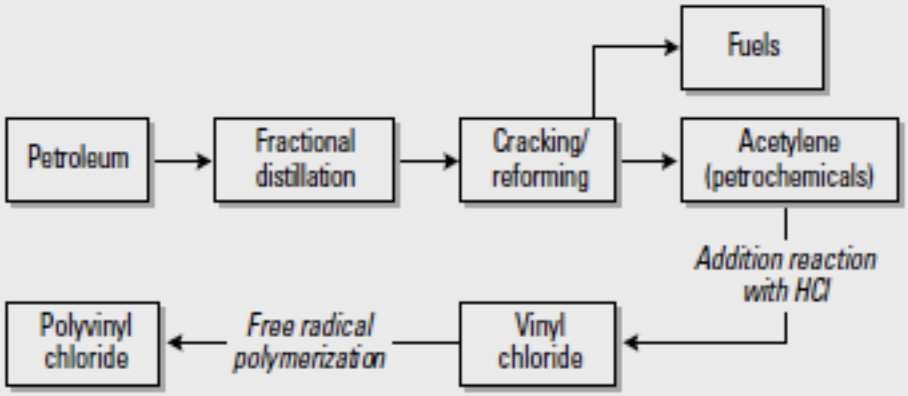
(b) Bromine is classified as highly volatile, toxic, and may cause severe burns to exposed tissue. All chemical tests should be performed in a fume hood; any spills should be immediately cleaned up. All waste products should be discarded into a container labelled "halogenated organic waste" for proper disposal by qualified lab personnel.

(c) This is an addition reaction. The color change indicates the disappearance of the bromine in solution to form 2,3-dibromobutane.

(d)



20.



21. (a) The development of organic fuel additives such as methyl tertiary-butyl ether (MTBE) allows for the use of lead-free fuels in automobiles and helps reduce the amount of lead, a heavy metal toxin, being released into the environment.

(b) Used polyethylene terephthalate (PET) is fully recyclable because, unlike other plastics, the polymers can be recovered. This is due to the fact the terephthalic acid (TPA) or dimethyl terephthalate (DMT) monomers used to produce the polymer give it a low melting temperature and so makes it easy to reform.

22. There are many possible answers. One useful method is to question whether the author of the article or web site stands to gain financially if they convince individuals that their argument is valid. To assess the possibility of bias it is often useful to look at the mission statements or goals of any sponsoring organization for that author. Few sponsors allow for a purely unbiased treatment. In addition, sources that are peer-reviewed by other individuals in that research community tend to be less biased, since experimental data supporting the author's claim is scrutinized.

23. The properties that make plastics so useful include their ability to be made into any desired shape, and their ability to bend and warp without breaking.

24. One useful way to increase the efficiency of recycling in any community is to decrease the amount of category 3 through 7 plastics. The economic and logistical difficulties in recycling these plastics means that they are merely put into landfills at present. If consumers buy items that have plastics from categories 1 and 2, they can increase the likelihood of re-use because the plastics can be easily recycled.

25. (a) Currently the production of biofuels is limited by technological problems. It is not cost effective to work directly with cellulose so the industry uses biological fermentation to produce methanol and ethanol. These alcohols provide less energy than gasoline when combusted and so are relatively expensive to use. In addition, the infrastructure to deliver biofuels to consumers is lacking.

(b) Unlike fossil fuels, biofuels are ultimately a renewable resource and tend to be cleaner burning to produce less greenhouse gas emissions.

(c) In Alberta, the petroleum industry would need to be retooled to focus less on fuels and more on petrochemicals, which is an expensive undertaking. In addition, the agricultural sector would need to focus on growing plants that are not used for food or fibre.

(d) Student should be able to provide a rationale for their opinion. A good way to focus on this is to have students make a list of pros and cons for comparison.

26. Students who disagree are likely to include reasons that focus on the extreme usefulness of synthetic polymers for things such as clothing and building materials. Those students who agree are likely to focus on the environmental release of toxins or current demand on non-renewable fossil fuels to produce those polymers.

27. The amino acids in the beverage are the monomers used to form protein in muscles. Athletes might believe that if they increase the amount of amino acids they consume, it will result in an increase in muscle mass.

28. Ensure that models for both starch and cellulose are built so that students can see the different three-dimensional structures for these molecules.